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COOPERATIVE GROUNDWATER REPORT 9
ILLINOIS STATE WATER SURVEY
ILLINOIS STATE GEOLOGICAL SURVEY
Champaign, Illinois 61820

**RETENTION OF
ZINC, CADMIUM, COPPER, AND LEAD
BY GEOLOGIC MATERIALS**

James P. Gibb and Keros Cartwright

Prepared in cooperation with
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency

STATE OF ILLINOIS
DEPARTMENT OF ENERGY AND NATURAL RESOURCES

1982

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Table 12. Total Mineral Analyses Data for Control Holes — Site B

	Control Hole 1S		Control Hole 1D	
	mg/l	me/l	mg/l	me/l
Fe	90.		1.7	
Mn	3.80		0.07	
Ca	72.0	3.59	80.0	3.99
Mg	24.9	2.05	33.2	2.73
Sr	0.36	0.01	0.13	
Na	169.	7.35	60.2	2.62
K	2.0	0.05	0.4	0.01
NH ₄	0.7	0.04	Tr	Tr
Ba	0.3		<0.1	
Cd	0.00		0.00	
Cr	0.00		0.00	
Cu	0.00		0.00	
Pb	<0.05		<0.05	
Li	0.01		0.00	
Ni	<0.05		<0.05	
Zn	0.00		0.00	
PO ₄ (filt)	0.0		0.0	
PO ₄ (unfilt)	3.4		0.1	
SiO ₂	16.6		20.2	
F	0.9		0.4	
B	0.2		0.0	
NO ₃	0.3	Tr	18.2	0.29
Cl	130.	3.67	10.	0.28
SO ₄	8.6	.18	149.3	3.11
Alk. (as CaCO ₃)	460.	9.20	286.	5.72
Hard. (as CaCO ₃)	282.	5.64	336.	6.72
TDM	698.		543.	

tation are the principal attenuating mechanisms. The geology at Site B is similar to that at Site A, and therefore desirable for this type of waste disposal activity. The topography of this site is steeper, resulting in better drainage and less downward migration of the metals. The ability to define the migration patterns of the metals with fewer core holes and piezometers attests to the similarity of the sites and to the knowledge gained at Site A.

Site C

Site C is a secondary zinc smelter located in north-central Illinois. It was a primary smelting facility from 1906 until 1971 when it was converted to secondary smelting operations. Wastes from the plant principally have been in the form of metals-rich cinders, as at Sites A and B. There currently is a 40-foot-high pile of cinders covering about 12 acres in the southeast portion of the plant property. A 1- to 5-foot-thick layer of cinders also covers the remaining 90 acres of the plant complex.

This site was selected because it lies along the Illinois River in an alluvial sand and gravel setting. It also is compatible with Sites A and B with regard to the pollution source (zinc) and period of operation. A

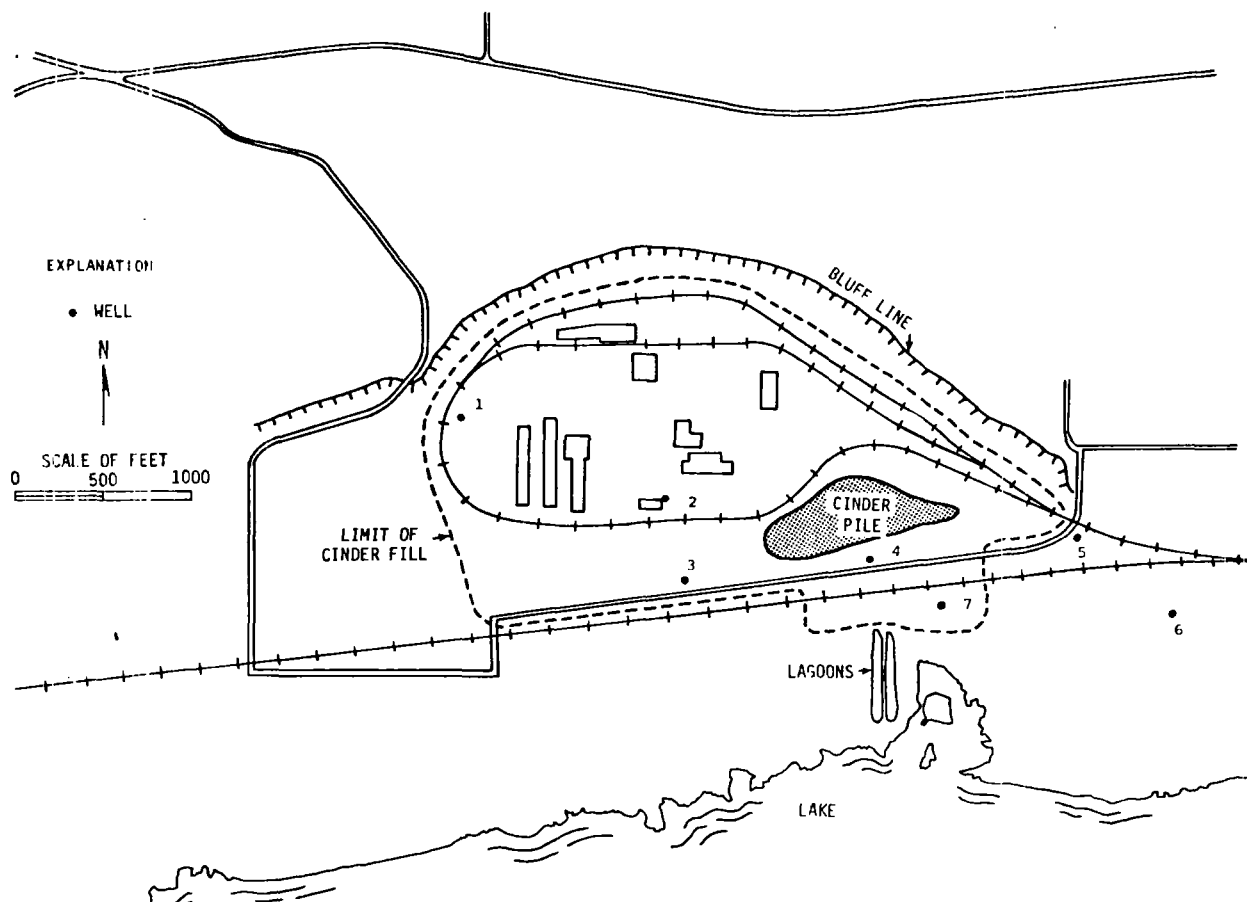


Figure 35. Location map — Site C

limited number of core holes and wells (7 core holes and 14 wells at 7 locations) were constructed at this site (Figure 35). Total well and coring footages are about 347 and 185 feet, respectively.

Geology

The stratigraphic units at Site C differ markedly from those at the other locations. The site is situated on a low level outwash terrace at the edge of the Illinois River floodplain. The outwash (Henry Formation) varies in character and thickness across the site. At the eastern edge of the property, the Henry Formation is predominantly overlain by swamp deposits (Grayslake Peat). Figure 36 shows a cross section which illustrates the nature of the deposits at the site. Data for selected borings are included in the Appendix. No textural or mineralogical analyses were run on the samples collected at this location. Bedrock was not encountered in any of the borings, so the exact thickness of the unconsolidated sediments is unknown. However, available data suggest that the unconsolidated materials are 50 to 100 feet thick, thinning eastward. The stratigraphy developed during this investigation corresponds with previous work in the area by Willman (1973). A brief description of the stratigraphic units follows.

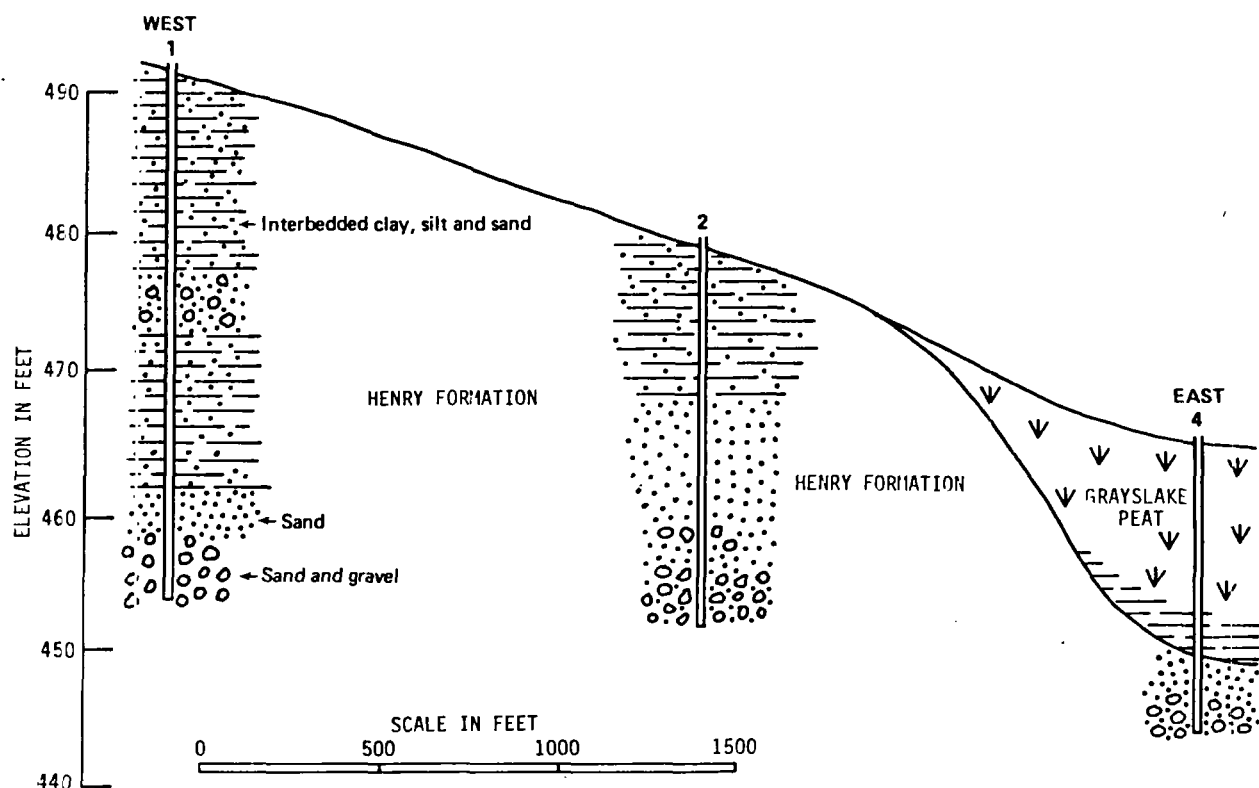


Figure 36. Stratigraphic cross section – Site C

Holocene Stage

- A) Grayslake Peat (0 to 20 feet thick) - Recent accumulation of peat, marl, and muck locally interbedded with silt and silty sand. Light gray to dark gray to black; organic material including wood fragments is abundant. Contains carbonates except at the surface. Represents accumulation of organic material in a wet, poorly drained environment. Silt loam at the base overlying the Henry Formation may represent a transition from alluvial to swampy environment.

Wisconsinan Stage

- B) Henry Formation (3 to 38 feet thick) - Interbedded clay, silt, sand, and gravel. Predominantly silt and clay in upper portion (see Figure 36); probably contains slopewash from adjacent bluffs, especially in the western part of site. Considerable variation in texture vertically and laterally (Figure 36). Typically becomes coarser with depth; sand and gravel are predominant. Contains carbonates except where leached at the surface. Deposited by meltwaters from the Wisconsin glaciers carrying sediment down the Illinois River Valley. Contains poorly developed Modern Soil; has probably been disturbed by human activity. It is at the surface in the western portion of Site C and underlies the Grayslake Peat in the eastern part of the site.

Hydrology

On the basis of the geologic description of this site, it is obvious that there is a thick permeable sand and gravel deposit associated with the Illinois River lowlands. Two wells owned by the industry are capable of yielding in excess of 500 gallons per minute each.

To determine the hydraulic characteristics of this aquifer a pumping test with 1 observation well (4D) was conducted on August 31, 1976. To allow for a larger pumping rate during the test, an 8-inch-diameter test well (TW1) was constructed 8 feet east of 4D. The well was 32 feet deep and equipped with 10 feet of 7-slot (0.007 inch) wire-wound screen. The well penetrated the top 10 feet of the aquifer.

The well was pumped at a constant rate of 30 gallons per minute for a period of 135 minutes and allowed to recover for a period of 80 minutes. Drawdown and recovery data for wells TW1 and 4D are presented in Figure 37.

Analyses of these data were complicated by the following factors: a) the effects of stored water in the casing were experienced because of the low pumping rate relative to the well diameter; b) most theoretical solutions for type curves require the assumption that flow is uniform through all sections of the well screen (under ordinary circumstances this assumption is valid, but in this case it cannot be accepted because of the closeness of the observation well); and c) the production well (TW1) is partially penetrating at only 17.2 percent, and this low a percentage does not appear in tables of well functions found in the literature.

To solve for the above situation, type curves were generated to fit the field conditions. A modified form of a computer program given by Prickett and Lonquist (1971) was used. Their program was modified to operate in a vertical cross section with radial symmetry about the center of the production well. The program also was transformed to yield a nondimensional well function. The well function for nonleaky aquifers, $W(u)$, used at site A is an example of a mathematically generated type curve. The well function generated in this case is termed $(W[u(r/m)r])$ since the drawdown also is a function of the ratios of observation well distance to the aquifer thickness (r/m) and the production well screen length to the aquifer thickness (L/m).

Figures 37a and b show the resulting type curve analyses for the pumped well and observation well, respectively. Since the effective radius of the pumped well is unknown, results of analysis from the pumped well data are considered only an approximation. The accepted computed coefficients of transmissivity, hydraulic conductivity, and storage are 127,000 gpd/ft, 2190 gpd/ft², and 0.094, respectively.

The computed storage coefficient is unexpectedly high. This could be caused by some leakage from materials overlying the defined aquifer. Another possible explanation is the presence of the cinder pile next to the pumping test site. Lowering of water levels by pumpage may allow additional compaction of the aquifer materials under the weight of the cinder pile, resulting in an apparently higher storage coefficient value.

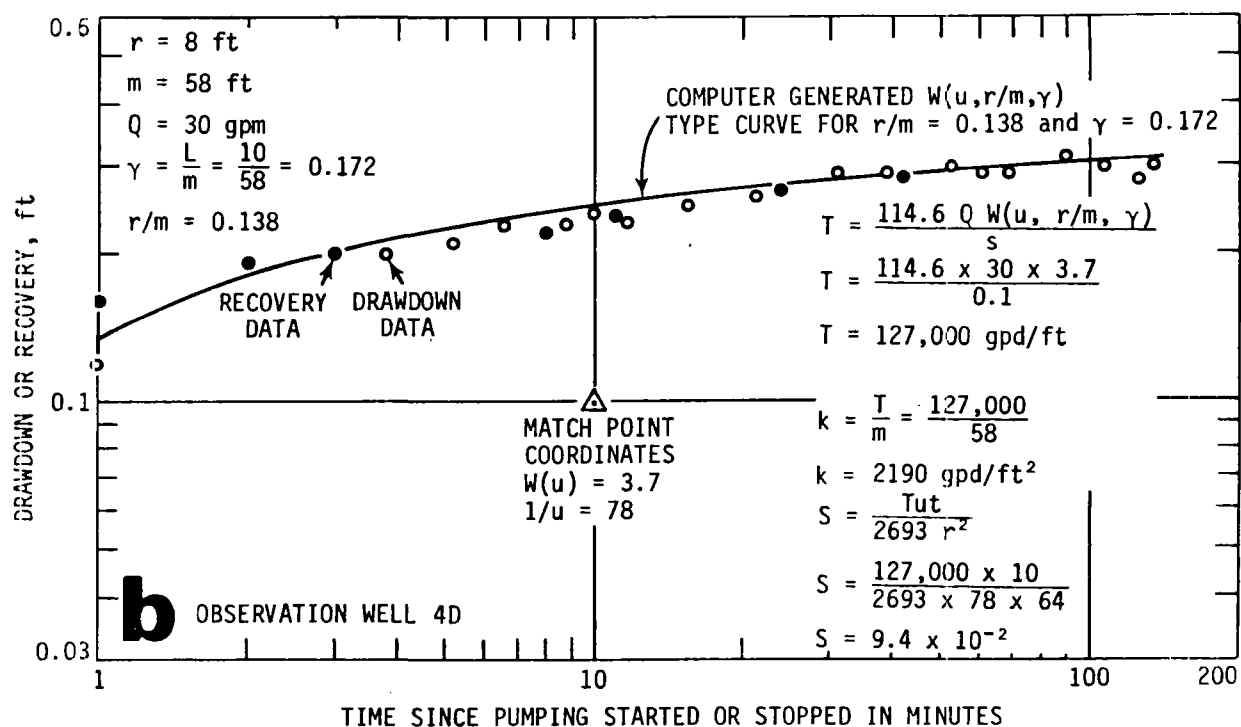
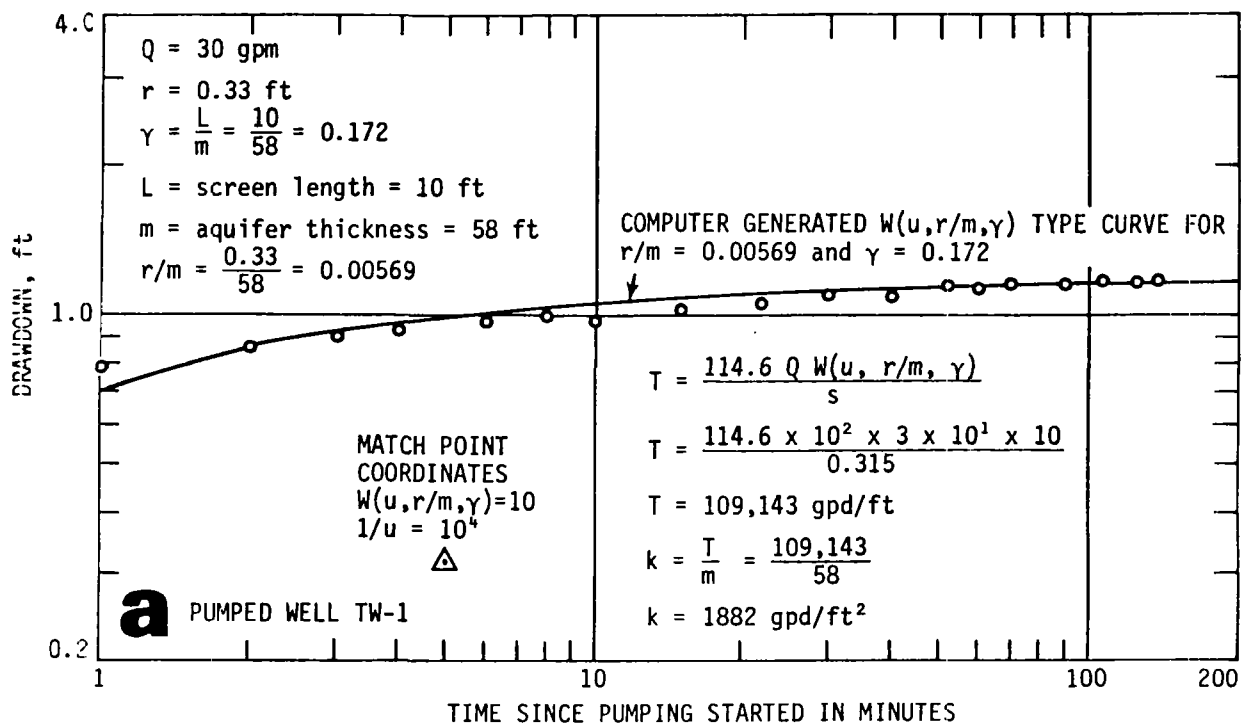


Figure 37. Pumping test data for wells TW1 and 4D – Site C

In an effort to detect any possible shallow groundwater contamination at this site, a series of wells were constructed about 5 to 10 feet below the water table surface and another series of wells were installed about 10 to 15 feet below that. Water level hydrographs for the shallow and deep wells are presented in Figure 38.

Piezometric surface maps were drawn for each round of water level measurements made. Figures 39a and b illustrate the high and low water level configurations for June 1976 and October 1976, respectively. The general direction of groundwater movement is to the south toward the backwater lake and the Illinois River.

Water levels in the deeper wells varied in response to precipitation in a fashion similar to that of the shallow wells. At wells 1 and 2 the vertical movement of water in the drift materials is downward. At all other sites, those closer to the river, the direction of vertical movement is upward. Maximum and minimum water levels for all wells at Site C are summarized in Table 13.

To determine the rate of groundwater movement Darcy's equation was applied as at Site A. On the basis of data presented by Todd (1967), an effective porosity or specific yield of 0.20 was assumed for the aquifer materials. The average rates of movement for June and October 1976 were 23 and 18 ft./day, respectively. These relatively high rates of groundwater movement were to be expected in a permeable sand and gravel aquifer of this type.

A soil temperature survey was made at Site C on April 14 and 21, 1976. The locations of the 44 stations are shown in Figure 40. All temperature readings were normalized to the April 14 conditions. The soil temperatures were measured at a depth of 2.3 feet and corrected for depth to the water table by methods given by Cartwright (1968). Lines of equal temperature on a contour interval of two degrees Fahrenheit are shown in Figure 40. High soil temperatures were measured in the area surrounding the complex of industrial buildings. High soil temperatures measured in low ground south of the high mound of cinders are caused by groundwater discharge. At the season of the year when the soil temperature measurements were made, a warm anomaly is expected in areas of groundwater discharge. Groundwater discharge in the vicinity of the cinder pile may be receiving contributions from the regional flow system as well as from locally mounded groundwater in the cinder pile. Groundwater discharge from the cinder pile may be highly contaminated.

The inferred direction of groundwater flow for the study area, as interpreted from the soil temperature, is southward toward the lake. This compares favorably with the direction of groundwater movement determined from water level data (see Figure 39).

Chemical Data

In addition to the analyses of data for geologic interpretation, chemical analyses of the core samples were conducted to define the migration characteristics of the suspected contaminants through the sandy soil

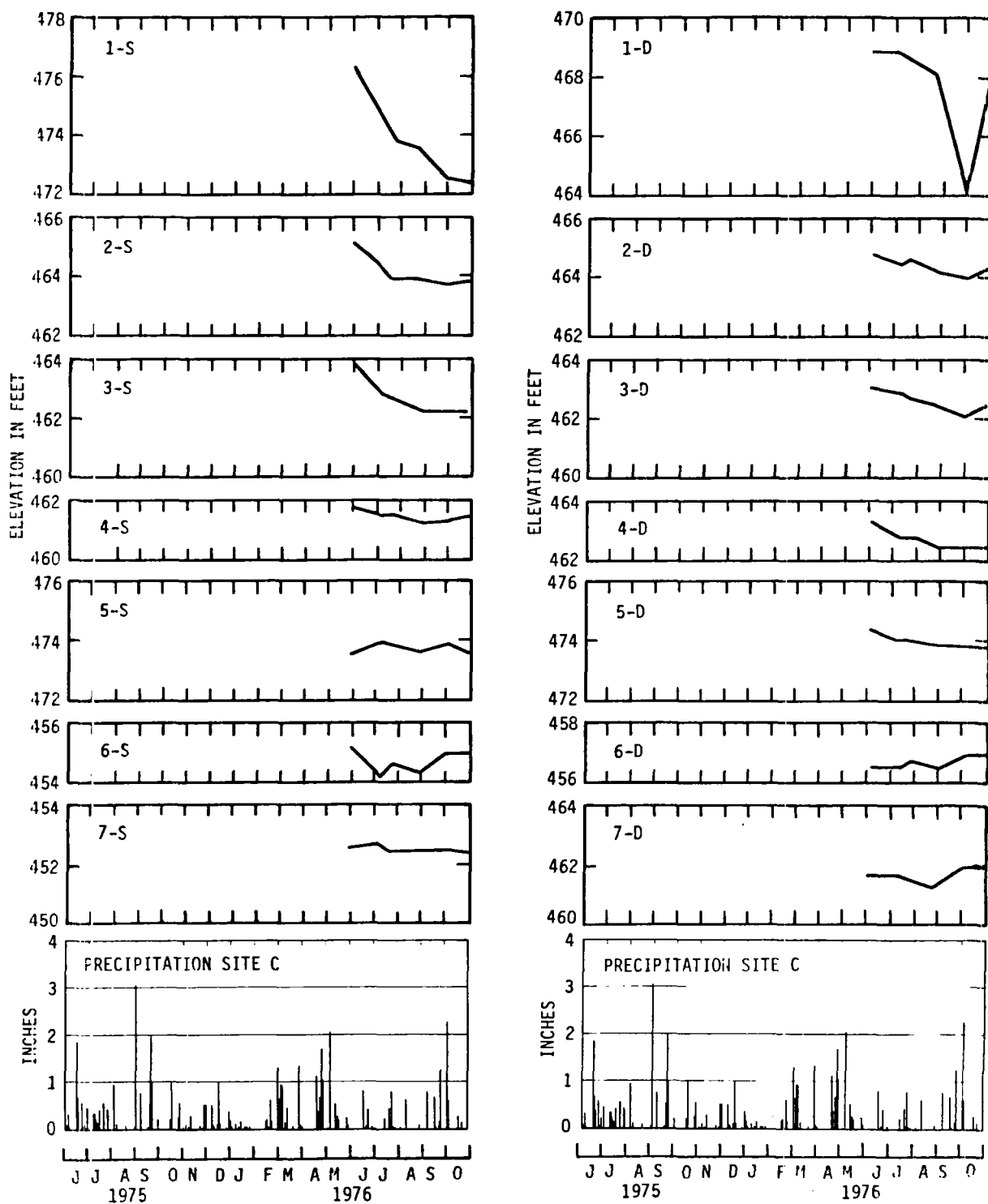


Figure 38. Water level hydrographs for all wells – Site C

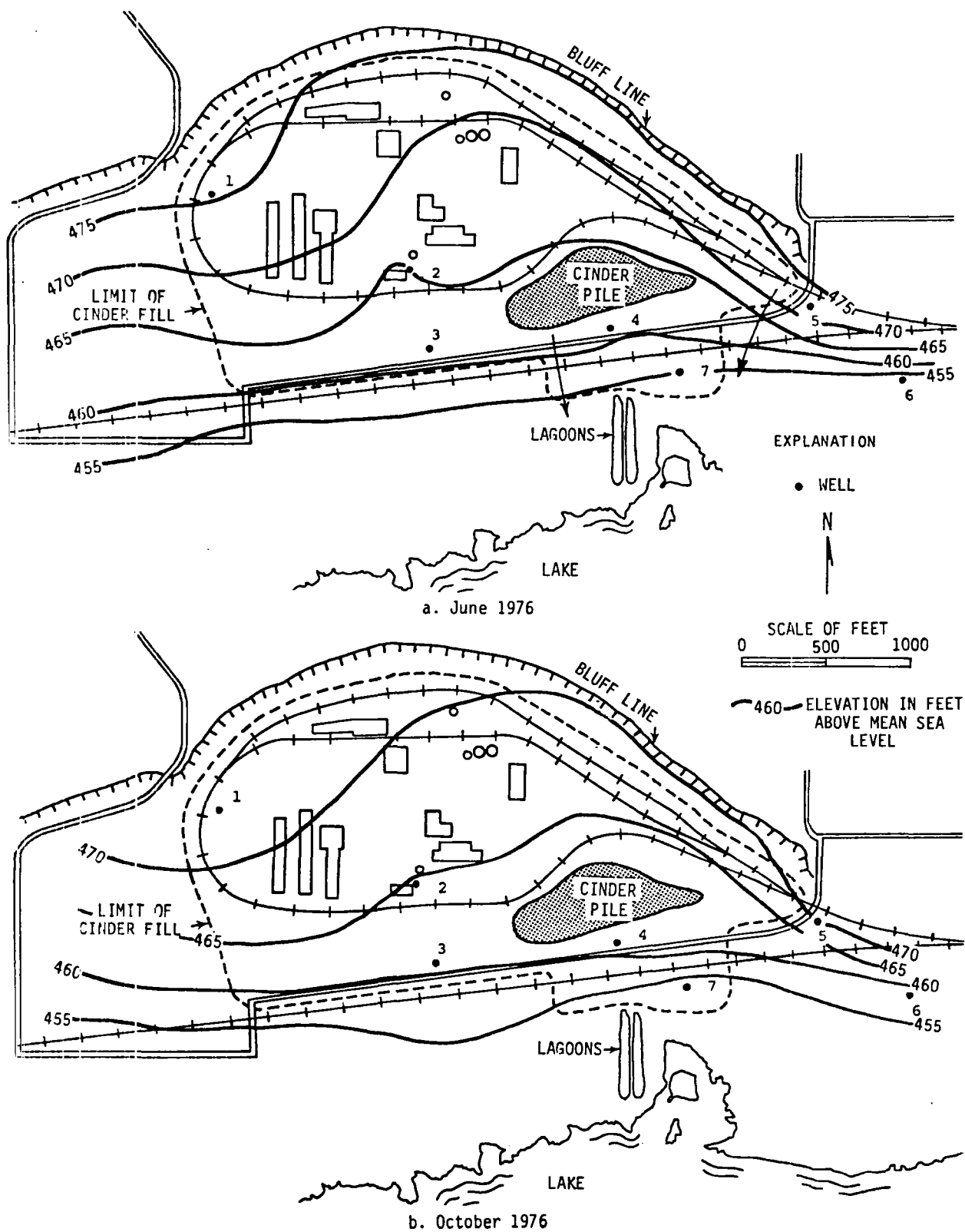


Figure 39. Piezometric surface maps for a) June 1976, and b) October 1976, for shallow wells at Site C

Table 13. Range of Water Level Fluctuations in All Wells – Site C

Well	Land surface elev (ft)	Low			High			Fluctuation (ft)
		Depth below land (ft)	Mean sea level (ft)	Date	Depth below land (ft)	Mean sea level (ft)	Date	
1S	490.98	18.54	472.44	10-26-76	14.56	476.42	6-1-76	3.98
1D	491.04	26.95	464.09	9-29-76	22.20	468.84	7-8-76	4.75
2S	478.92	14.81	464.11	9-29-76	13.32	465.60	6-1-76	1.49
2D	478.76	14.91	463.85	9-29-76	13.02	464.74	6-1-76	1.89
3S	469.58	7.35	462.23	8-24-76	5.68	463.90	6-1-76	1.67
3D	469.88	7.90	461.98	9-29-76	6.92	462.96	6-1-76	0.98
4S	464.82	3.50	461.32	9-29-76	3.02	461.80	6-1-76	0.48
4D	464.66	2.29	462.37	9-29-76	1.41	463.15	6-1-76	0.78
5S	473.56	0.08	473.48	6-1-76	-0.35	473.91	7-8-76	0.43
5D	473.65	-0.19	473.84	10-26-76	-0.79	474.44	6-1-76	0.60
6S	456.29	2.04	454.25	7-8-76	1.00	455.29	6-1-76	1.04
6D	456.37	-0.03	456.40	8-25-76	-0.49	456.86	10-26-76	0.46
7S	467.29	14.98	452.31	10-26-76	14.67	452.62	7-8-76	0.31
7D	467.08	5.74	461.34	8-25-76	5.08	462.00	10-26-76	0.66

S = shallow; D = deep

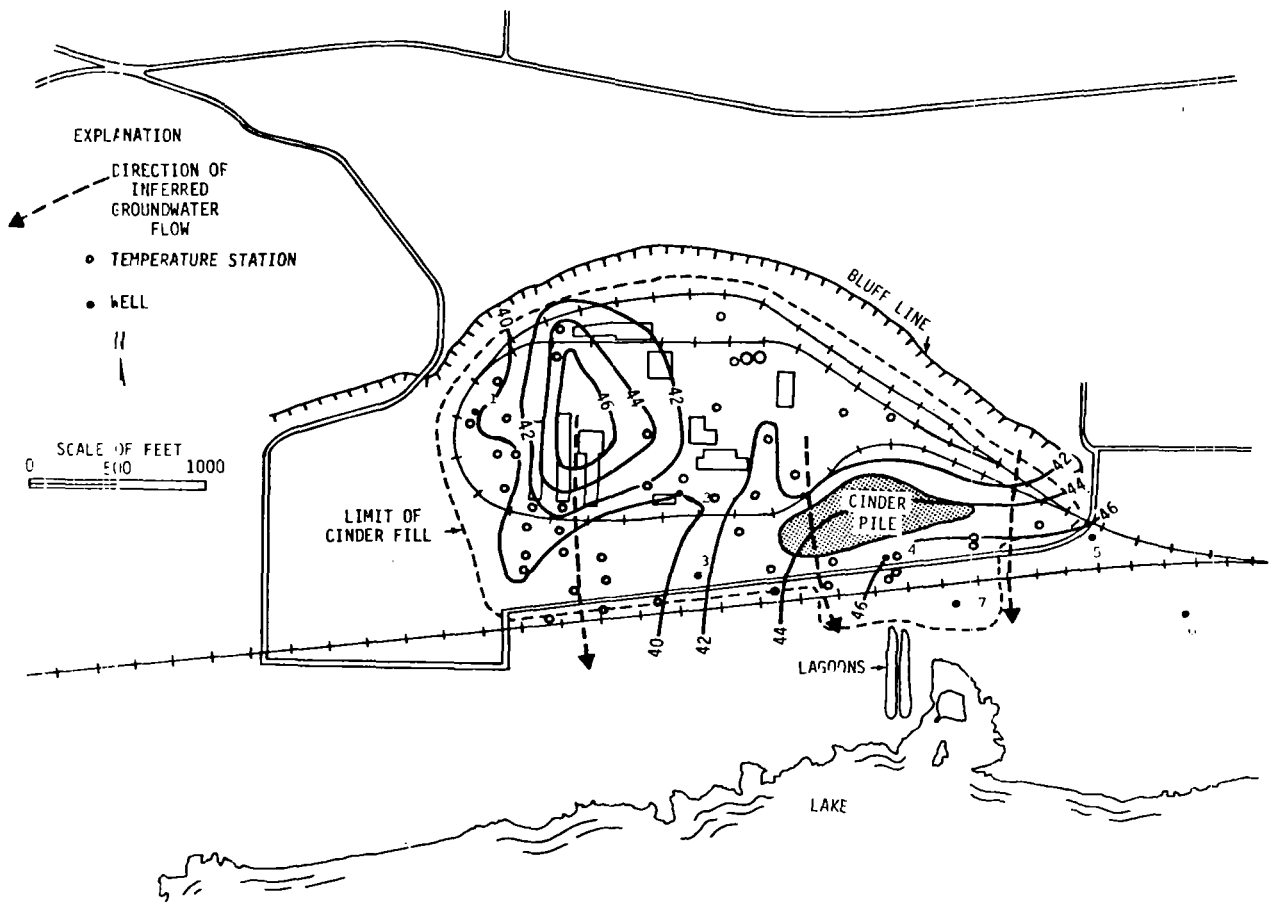


Figure 40. Soil temperature stations and results – Site C

and the effectiveness of these soils in retaining the metal contaminants. Selected analyses are given in the Appendix. As at sites A and B, four elements -- zinc, cadmium, copper, and lead -- were routinely determined.

No control hole was constructed at this site because of the limited time and money available. However, data from the lower segments of all holes at this site suggest that the background concentrations found in the control holes at Sites A and B also are valid at this site. Zinc concentrations in the lower portions of the seven core holes ranged from about 13 to 75 mg/l, cadmium from less than 0.6 to 0.90 mg/l, copper from about 10 to 25 mg/l, and lead from less than 4.0 to 90 mg/l.

The number and locations of core holes at this site were not adequate to define the limits of horizontal migration of the metals in the soil. However, the vertical migration patterns are very similar to those at Sites A and B.

Holes 1, 2, and 3 are located on relatively upland portions of the plant complex. Zinc concentrations in excess of 10,000 mg/l were present in the cinder fill material at the surface. Below the fill, zinc concentrations generally decrease downward through the soil profile in which carbonates have been leached. Cation exchange is the major mechanism of attenuation in this interval.

Below the zone of leaching, carbonates are present, and the pH is assumed to be about 7 to 8. The increase in soil pH causes precipitation to be an important factor in attenuation and is reflected by an increase in zinc concentrations. Examination of the core samples indicates accumulations of zinc carbonate in samples with extremely high zinc levels.

The clays present in the fine-grained surficial geologic material are responsible for a rapid decrease in zinc concentrations just below the cinder fill material, just as at Sites A and B. However, the Henry Formation becomes coarse grained with depth, and appears to be less effective in attenuating zinc movement by cation exchange. The zinc concentrations drop off quickly to background levels below a depth of 16 to 17 feet as a result of the combined action of cation exchange and precipitation.

Holes 4, 5, and 7 also are similar to each other. At each of these locations the fill materials are underlain by the Grayslake Peat, and migration into these highly organic materials is minimal. Information for hole 4 indicates that in addition to cation exchange, soil pH also is a major factor contributing to attenuation. Hole 6 is lowland swampy area with the Grayslake peat at the surface and extending to a depth of about 19 feet. The repeated inundation of this location with high metal content surface water has resulted in zinc migration to a depth of about 6 feet into the peat. Analyses of the lake bottom sediments south of the plant indicate that large quantities of heavy metals have left the plant site by surface water mechanisms (Table 14). The metal contents of the lake bottom sediments can be compared with those of the stream bottom sediments at Sites A and B.

Table 14. Concentrations (mg/l) of Trace Elements in Bottom Sediments
from Backwater Lake South of Site C

<i>Depth (inches)</i>	Pb	Zn	Cd	Cu
0-3	141	5000	52	128
3-6	119	5000	34	119
6-9	183	4100	104	130
9-12	211	3400	116	109
12-15	42	348	6	47

Vertical migration of cadmium at each location was very similar to that of zinc. Copper and lead above the assumed background levels were limited to the fill materials, indicating little or no vertical migration of these metals into the underlying soils.

The mechanisms retaining the metals in the soil profile at this site are the same as at Sites A and B. Since no cation exchange capacities were determined for core samples at this site, no comparisons can be made concerning the relative effectiveness of the sandy soils versus the clays, silts, and tills. Results of many laboratory studies suggest that the sandy soils would be less effective as an exchange material, although it would be very difficult to substantiate those results from the data collected in this study. However, there does appear to be clear evidence of the high exchange capability of the organic materials at this site.

Zinc concentrations in water samples collected from wells at Site C are presented in Table 15. All deep wells, those finished 15 to 20 feet into the aquifer, produced water containing less than 0.5 mg/l zinc. Wells 1S and 4S produced water containing less than 0.3 to 16.6 mg/l zinc and less than 0.5 to 69.5 mg/l zinc, respectively. As discussed earlier, a large part of this sizable variation in zinc content may be a result of our sampling protocol. In addition, the close proximity of 4S to the cinder pile and the probable resulting highly mineralized water may have affected the well seal. If the first sample (June 1, 1976) had been affected by the drilling process, the gradual failure of the well seal could explain the results of the remaining samples.

The work conducted at this site was limited in scope but substantiates the findings at Sites A and B. The site was selected because it is a sandy environment that poses core sampling problems not encountered at the other sites, and because the effectiveness of sandy soils to retain metals is reportedly low.

The relatively shallow penetration depth of metals concentrations was somewhat surprising. The silty surface materials overlying the sand aquifer and highly organic peat deposits appear to be retaining significant quantities of the metals. The fact that no large amounts of zinc were found in the aquifer indicates that it has not entered the aquifer or else

Table 15. Zinc Concentrations in Water Samples from Wells at Site C
(Concentrations in milligrams per liter)

	1976			
	6-1	7-8	7-27	8-25
1S	0.3	13.	16.6	2.7
1D	*	*	*	*
2S	*	*	*	*
2D	*	*	*	*
3S	*	*	*	*
3D	*	*	*	*
4S	69.5	*	4.6	12.1
4D	*	*	*	*
5S	*	*	*	*
5D	*	*	*	*
6S	*	*	*	*
6D	*	*	*	*
7S				
7D	0.3		*	*

S = shallow; D=deep

* = values less than 0.5 mg/l

is entering it at such a slow rate compared with the regional flow system that it is undetectable.

The data are not sufficient to indicate that this type of geology provides an adequate environmental barrier for this type of disposal activity.

SECTION 6

CONCLUSIONS

1. The vertical and horizontal migration patterns of zinc, cadmium, copper, and lead were defined throughout the soil and shallow aquifer systems at Sites A and B. Vertical migration patterns of the same elements were successfully defined at Site C. In all three cases zinc proved to be the most mobile, followed by cadmium, copper, and lead, in that order.

2. The contamination which occurred at the three zinc smelters has been contained in the general plant areas by attenuation processes in the soil, despite the long period of time and the heavy surface loading of the systems with zinc and other heavy metals. Sites A and B are located in regions generally considered geologically acceptable for such waste disposal. Site C is in what generally is regarded as a sensitive environment for waste disposal, and may not attenuate constituents that are more mobile than those studied here.

3. Two principal mechanisms control the distribution of zinc and other metals at Sites A, B, and C. These are, in order of dominance, cation exchange and precipitation of insoluble metal compounds as a result of pH changes in the infiltrating solutions.

4. Soil coring has been demonstrated to be an effective investigative or research tool in this project. However, proper geologic interpretation and a thorough understanding of soil chemistry is essential to effective use of the technique. Cost analyses and experience gained during this project suggest that coring has limited application to routine groundwater monitoring cases.

5. The use of piezometers or wells for routine monitoring probably is most cost effective and most easily managed. A limited amount of core sampling would provide data for better vertical and horizontal placement of almost all monitoring wells.

6. Proper sampling techniques for collecting representative water samples from monitoring wells have not been determined. Results of a brief experiment in this study suggest that variations as great as 45 to 80 percent in the chemical constituents of water samples could result from improper sampling techniques. Difficulty also was experienced with leakage of surface water through ineffective well seals.

7. Field investigations with geophysical methods show that electrical earth resistivity and soil temperature measurements can be used to gather information rapidly and economically on the lithology of the geologic materials, to define the shallow groundwater flow system and to identify possible zones of contaminated groundwater within the flow system.

8. Geologic environments consisting predominantly of clay, silt, and clay-rich tills have been demonstrated to be effective in retaining the movement of the metals zinc, cadmium, copper, and lead from very concentrated inorganic sources.

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APPENDIX. DATA FROM SELECTED BORINGS

Abbreviations and Symbols

W	moisture content	Cal	calcite
Gs	specific gravity	Dol	dolomite
Gvl	gravel	cts/sec	counts per second
Sd	sand	Zn	zinc
St	silt	Cd	cadmium
Cl	clay	Cu	copper
DI	diffraction index	Pb	lead
M	montmorillonite	CEC	cation exchange capacity
I	illite	N.D.	not detectable
C-K	chlorite-kaolinite	L.S.	land surface



Soil developed



Clay or accretion-gley



Sand



Till



Silt



Bedrock

(6-60-34), etc. = Average percentage of sand-silt-clay excluding gravel

No.	SITE A 2 L.S. = 507.83			Engineering Data				Grain Size			
	Depth of Sample (ft)	Unit Description	Graphic Log	W %	Gs	Void Ratio	Dry Den #/ft ³	Gv %	Sd %	St %	Cl %
1	0.5-1.0	PEORIA LOESS (6-60-34)		-	-	-	-	1	7	71	20
2	1.0-1.5			-	-	-	-	-	-	-	-
3	1.7-2.2			-	-	-	-	0	4	57	39
4	2.7-3.2			-	-	-	-	1	6	56	38
5	3.2-3.7			-	-	-	-	-	-	-	-
6	3.7-4.2			-	-	-	-	1	5	57	38
7	4.2-4.7			24.2	2.76	-	-	-	-	-	-
8	4.7-5.2	ROXANA SILT (24-40-36)		-	-	-	-	1	17	52	31
9	5.8-6.3			-	-	-	-	1	19	44	37
10	7.3-7.6			-	-	-	-	-	-	-	-
11	7.7-8.2			-	-	-	-	2	30	33	37
12	8.1-9.6	BERRY CLAY (37-31-32)		-	-	-	-	2	31	30	39
13	9.7-10.2			-	-	-	-	1	28	36	36
14	10.7-11.2			-	-	-	-	2	33	31	36
15	11.3-11.8	HAGARSTOWN		-	-	-	-	10	39	29	32
16	12.4-12.7			-	-	-	-	-	-	-	-
17	12.7-13.2			-	-	-	-	3	51	27	22
18	13.2-13.7	GLASFORD FORMATION TILL (29-40-31)		-	-	-	-	-	-	-	-
19	13.7-14.2			-	-	-	-	4	44	38	18
20	14.7-15.2			-	-	-	-	7	37	37	26
21	15.7-16.2			-	-	-	-	5	41	33	26
22	16.2-16.7			-	-	-	-	-	-	-	-
23	17.7-18.2			-	-	-	-	4	35	36	29
24	18.2-18.7			-	-	-	-	-	-	-	-
25	18.7-19.2			-	-	-	-	5	30	45	25
26	19.5-20.0			-	-	-	-	3	32	40	28
27	20.1-20.6			13.5	2.70	.39	122	-	-	-	-
28	20.6-21.1			-	-	-	-	3	28	43	29
29	21.7-22.2			-	-	-	-	4	28	39	33
30	22.7-23.2			-	-	-	-	3	35	37	28
31	23.7-24.2			-	-	-	-	3	30	39	31
32	24.2-24.7			15.8	2.70*	.45	117	-	-	-	-
33	24.7-25.2			-	-	-	-	4	30	41	29
34	25.2-25.7			-	-	-	-	-	-	-	-
35	25.7-26.2			-	-	-	-	5	30	40	30
36	26.7-27.2			-	-	-	-	8	27	42	31
37	27.7-28.2			16.7	2.70*	.41	119	-	-	-	-
38	29.5-30.0			-	-	-	-	3	30	38	32
39	31.5-32.0			-	-	-	-	3	26	38	36
40	32.7-33.2			-	-	-	-	5	29	40	31
41	33.7-34.2			-	-	-	-	5	29	41	30
42	34.2-34.7			-	-	-	-	-	-	-	-
43	34.7-35.2			-	-	-	-	3	30	38	32
44	35.2-35.7			16.8	2.70*	.43	118	-	-	-	-
45	36.2-36.7			-	-	-	-	3	27	42	31
46	36.9-37.4			-	-	-	-	1	22	41	37
47	37.7-38.2			-	-	-	-	1	20	40	40
48	38.7-39.2			-	-	-	-	14	33	37	30
49	39.3-39.7			-	-	-	-	-	-	-	-
50	39.7-40.2			-	-	-	-	1	18	49	33
51	42.0-42.5			-	-	-	-	4	29	41	30